

# KEEPING PAIN OUT OF YOUR MIND: THE ROLE OF ATTENTIONAL SET IN PAIN

Running head: The role of attentional set in pain

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What's already known about this topic?

- Directing attention towards a task unrelated to pain is mostly found to diminish self-reported pain
- Involuntary capture of attention by pain is to some extent controlled by top-down processes

What does this study add?

- The interplay between attention and pain is not fully captured by simple resource models.
- The experience of pain depends on the degree to which task-relevant features are distinct from pain-related features.

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## **Abstract**

**Background:** The involuntary capture of attention by pain may to some extent be controlled by psychological variables. In this paper we investigated the effect of attentional set (i.e. the collection of task-related features that a person is monitoring in order to successfully pursue a goal) on pain.

**Methods:** Two experiments are reported in which the task relevance of the modality and spatial location of a target stimulus was manipulated. In both experiments somatosensory and auditory stimuli were presented on each trial. In Experiment 1, 29 participants were cued on each trial to localize either a somatosensory or an auditory target. In Experiment 2, 37 participants were cued on each trial to identify either a somatosensory or an auditory target at a particular location.

**Results:** In Experiment 1, self-reported pain intensity and unpleasantness were reduced when participants had to localize the auditory target. The location of the painful stimulus relative to the location of the auditory target did not affect pain. In Experiment 2, again, pain intensity and unpleasantness ratings were reduced when participants identified the auditory target. Now, the location of the painful stimulus relative to the location of the auditory target

moderated the effect. Pain intensity was less when the painful stimulus was at a different location than the auditory target.

**Conclusions:** Results are discussed in terms of the attentional set hypothesis, and we argue that the effectiveness of distraction tasks depends on the degree to which the task-relevant features of the distraction task are distinct from pain-related features.

## **Introduction**

Pain has the ability to involuntarily capture attention at the expense of other ongoing activities (Bingel et al., 2007; Buhle et al., 2010; Legrain et al., 2009; Legrain et al., 2011c). Bottom-up features such as pain intensity, novelty, and unpredictability amplify task interference by pain (Crombez et al., 1994; Eccleston and Crombez, 1999; Iannetti et al., 2008; Legrain et al., 2009a). However, top-down control over attentional capture by pain is possible. Indeed, directing attention towards a task unrelated to pain diminishes the neural processing of nociceptive input (Legrain et al., 2009b; Tracey et al., 2007), self-reported pain (Van Damme et al., 2010), and task interference by pain (Legrain et al., 2011a; Legrain et al., 2011b).

A fundamental question is how exactly top-down control over pain is achieved. Most research on this topic has been informed by a limited capacity/resources model of attention and pain (McCaul and Malott, 1984), which assumes that pain will be less when cognitive tasks require more attentional capacity/resources. However, tests of this idea have mostly failed (McCaul et al., 1992; Seminowicz and Davis, 2007, but see Veldhuijzen et al., 2006). Recently, Legrain and colleagues (2009b) provided an integrative model describing how and when bottom-up and top-down variables interact in the attentional selection of pain. According to this model, top-down

control over pain by a cognitive task is not only dependent upon the overall effort needed to perform the task (attentional load), but also upon the availability of executive functions (e.g. the ability to inhibit automatic responses), and the precise content of the attentional set needed to perform the task. The latter refers to the collection of stimulus features that an individual keeps in mind in order to identify goal-relevant information (Yantis, 2000). The more features a stimulus shares with those in the attentional set, the more likely this stimulus will capture attention, even when it is completely irrelevant for the current goal (e.g. Folk et al., 1992). Attentional control over pain is probably also dependent upon the degree to which task-related features in the attentional set are distinct from pain-related features. The fewer shared features, the better attentional control over pain is expected to be. To the best of our knowledge, this idea has not yet been tested.

We tested the attentional set hypothesis in two experiments. On each trial somatosensory and auditory stimuli were presented, either at the same location or at a dissimilar location. In Experiment 1, on each trial participants were requested/cued to localize a target from one particular modality (either auditory or somatosensory) that equally often appeared at the left or the right hand. We predicted less pain when attending for an auditory target than attending for a

somatosensory target, irrespective of its location. In Experiment 2, on each trial participants were requested/cued to identify a target from one particular modality (either auditory or somatosensory modality) that appeared at one particular location (either left or right). We expected less pain when attending to an auditory target, particularly when pain was not at the attended spatial location.

## Experiment 1

### Method

#### *Participants*

Participants were 32 undergraduate students from Ghent University with normal or corrected-to-normal vision, who received course credits for participation (17 females; mean age =  $19.2 \pm 1.8$ , range 18-26, all Caucasian). Exclusion criteria were a self-reported neurological, psychiatric or chronic pain problem, or the current use of psychotropic or analgesic medications. Based on these criteria, three persons were excluded: two because of a chronic pain problem and one due to a major depression. In addition, one person was excluded due to the lack of valid pain ratings (i.e. ratings on trials with a correct response) in one condition of the critical trials. Experimental procedures were approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University, and written informed consent was obtained from participants.

#### *Apparatus and stimuli*

Somatosensory stimuli were either painful or non-painful stimuli. Painful stimuli were electrocutaneous stimuli delivered by a constant current stimulator (DS7A, Digitimer Ltd) and consisted of trains of 2ms pulses for a duration of 300ms (36 pulses; 6ms inter-



pulse-interval) and were delivered at the superficial branch of the median nerve on the wrists of both arms by two lubricated Fukuda standard Ag/AgCl electrodes (1cm diameter). Intensity of the electrocutaneous stimulus was 1.00 mA -below motor threshold- which is experienced as moderately intense and unpleasant (See Van Ryckeghem et al., 2011).

Non-painful stimuli were delivered by a vibration element. This element consisted of a Nokia 3210 vibromotor, enveloped by a plastic cylinder (1.3cm in diameter and 3.0cm long), which was attached next to the electrode sites by means of velcro. Tactile stimuli were administered for 300ms and had an instantaneous rise and fall time. Previous studies have shown that these stimuli are rated as less unpleasant than the electrocutaneous stimulus (See Van Damme et al., 2004a).

Auditory stimuli were tones (440Hz, 64 - 66dB (A)) presented through two loud-speakers (type, DELL A215) positioned approximately 35 degrees left and right from the middle (exactly next to participants' hands). Auditory stimuli were presented for 300ms and had an instantaneous rise and fall time.

### *Experimental task*

The experimental task was programmed and presented by the INQUISIT Millisecond software package (Inquisit 2.06, 2008) on an

Excel computer (Pentium 4, 2.8GHz, 512MB) with a 60-Hz, 17-inch colour CRT monitor. The experiment consisted of localising either the somatosensory stimuli (electrocutaneous or vibrotactile), or the auditory stimuli. Somatosensory and auditory stimuli were simultaneously presented on each trial. In 50% of the trials participants were instructed to localize whether the tone was presented to the left or to the right location (auditory relevant trials). On the remaining trials participants were instructed to localize whether the somatosensory stimulus was presented to the left or right location (somatosensory relevant trials). Each trial started with a visual cue consisting of a full coloured circle (either blue or yellow; 1000ms duration) in the centre of the screen that indicated which modality was relevant (colour of the cue and the associated target modality were counterbalanced). Somatosensory and auditory stimuli were presented equally often at the same location (spatially congruent trials) and at the opposite location (spatially incongruent trials). This resulted in four trial types: (1) spatially congruent/somatosensory relevant trials, (2) spatially incongruent/somatosensory relevant trials, (3) spatially congruent/auditory relevant trials, (4) spatially incongruent/auditory relevant trials. Each trial type was 'equi-probably' and randomly presented at the left and right location. Participants were instructed to

localize (right/left) the stimulus of the cued modality as fast as possible by speaking aloud “right” or “left”. Response latencies were recorded by a voice key (REACSYS R-51). Response errors were recorded by the experimenter on a trial to trial basis.

#### INSERT FIGURE 1

##### *Procedure*

Experimental duration was approximately 45 minutes. Upon arrival in the laboratory participants were told that “we were interested in the interplay between somatic stimuli and attention processes”. Furthermore they received task instructions and provided written informed consent. Participants were seated in front of the computer monitor. Next, participants were familiarized with the electrocutaneous stimuli by administration of two stimuli of increasing intensity (0.5mA, 1mA) to both arms (arm order was counterbalanced). To minimize expectancy about the stimulus intensity (which was kept constant during the experiment), participants were informed that the intensity of the electrocutaneous stimulus could vary during the experimental phase.

Next, participants performed 16 practice trials of the localisation task. Only vibrotactile stimuli were administered in this phase. Trials were presented with an inter-trial interval of 1000ms. When an error was made, or response latency exceeded 7000ms,

error feedback was given by way of presenting a red screen for 500ms.

In the experimental phase, participants performed a total of 128 trials. The trials were presented randomly with the same inter-trial interval and maximum response latency as in the practice phase. On 96 trials the somatosensory stimulus consisted of a non-painful vibrotactile stimulus. On 32 trials it consisted of a painful stimulus. Immediately after 25% of the trials with non-painful and 75% of the trials with painful stimuli, participants were asked to rate the intensity and the unpleasantness of the somatosensory stimuli. Ratings were electronically collected by means of two Likert scales presented on the screen. First pain intensity was assessed (range 0-10; 0='not at all intense; 10='very intense'), directly followed by the assessment of pain unpleasantness (range 0-10; 0='very pleasant'; 10='very unpleasant'). Trials with vibrotactile stimuli were filler trials, for two reasons. First, inclusion of these trials reduced the overall percentage of trials that were followed by a pain rating. So, the possibility that participants had attended to the somatosensory stimuli during auditory modality trials because they expected to rate the somatosensory stimuli was kept low (Eccleston, 1995). Indeed, only 48 of the 128 somatosensory stimuli were actually rated. Second, filler trials reduced the potential effects of habituation on the

perception of the painful stimulus (Crombez et al., 1997). After the experiment, participants completed questions related to socio-demographic characteristics. Participants were fully debriefed when data collection of the experiment was finished.

### *Data analyses*

Analyses were performed on the response latencies, pain intensity ratings and pain unpleasantness ratings of the electrocutaneous, i.e. painful, stimuli only. Trials with tactile stimuli (filler trials) were not analysed. Trials with voice key errors and during which an incorrect response was given (13%) were removed from the analyses. All variables were normally distributed (all Kolmogorov-Smirnov  $Z < 1$ ,  $p > .10$ ). For each dependent variable, a repeated-measures analysis of variance (ANOVA) with Modality Relevance (somatosensory relevant/ auditory relevant) and Location Congruency (spatially congruent/spatially incongruent) as within-subject factors was conducted. When appropriate, contrast analyses were used. Effect sizes and 95% confidence intervals (95% CI) were calculated for dependent samples (Borenstein et al., 2009; Cohen, 1988).

## Results

### *Response latency*

Before performing analyses, outliers were removed. Data with response latencies shorter than 200ms (anticipations) or larger than three standard deviations above the individual mean (outliers) were discarded from further analyses ( $\leq 2\%$ ).

The ANOVA on response latency showed a significant main effect of Spatial Congruency ( $F(1,27)= 5.37, p<.05, d=0.44$ ; 95% CI  $=0.05:0.82$ ), indicating that participants were faster when stimuli were spatially congruent ( $M=811$ ;  $SD=174$ ) than when stimuli were spatially incongruent ( $M=844$ ;  $SD=165$ ). Second participants tended to be faster to detect painful stimuli ( $M=812$ ;  $SD=170$ ), than to detect auditory stimuli ( $M=842$ ;  $SD=171$ ). Results however failed to reach significance ( $F(1,27)= 3.71, p=.06, d=0.36$ ; 95% CI  $=-0.02:0.75$ ). No interaction effect was found,  $F(1,27)<1.82, p>.10, d=0.25$ ; 95% CI  $=-0.12:0.63$ .

### *Self report data*

An ANOVA on self-report Pain Intensity showed a significant main effect of Modality Relevance ( $F(1,27)=27.75, p<.001, d=0.99$ ; 95% CI  $=0.54:1.45$ ), indicating that participants rated the pain as significantly less intense when attending to the auditory modality ( $M=4.48, SD=1.52$ ) than when attending to the somatosensory

modality ( $M=4.89$ ,  $SD=1.57$ ). The main effect of Spatial Congruency ( $F(1,27)=2.92$ ,  $p=.10$ ,  $d=0.32$ ; 95% CI  $=-0.07:0.70$ ) or the interaction between Modality Relevance and Spatial Congruency ( $F(1,27)<1$ ,  $d=0.09$ ; 95% CI  $=-0.28: 0.46$ ) were not significant.

#### INSERT FIGURE 2

The ANOVA on self-reported Unpleasantness showed a significant main effect of Modality Relevance ( $F(1,27)=14.95$ ,  $p<.001$ ,  $d=0.73$ ; 95% CI  $=0.31:1.14$ ), indicating that participants rated the painful stimulus as significantly less unpleasant when attending to the auditory modality ( $M=4.74$ ,  $SD=1.72$ ) than when attending to somatosensory modality ( $M=5.00$ ,  $SD=1.70$ ). The main effect of Spatial Congruency ( $F(1,27)=1.43$ ,  $p>.10$ ,  $d=0.23$ ; 95% CI  $=-0.15:0.61$ ) or the interaction between Modality Relevance and Spatial Congruency ( $F(1,27)= 1.42$ ,  $p>.10$ ,  $d=0.22$ ; 95% CI  $=-0.15:0.60$ ) were not significant .

#### **Discussion**

Results showed that the painful stimulus was experienced as less intense and less unpleasant when participants were instructed to localize the auditory target than when instructed to localize the somatosensory target. This finding is in line with previous studies which only manipulated the modality to which participants' attention was directed (e.g. Miron et al., 1989; Peyron, 1999). In this study we

however also manipulated the spatial location of the pain stimulus. The spatial location of the pain stimulus had no effect on the pain intensity and unpleasantness ratings. Overall, these results are in line with the attentional set hypothesis. When participants were instructed to localize the auditory target, the attentional set on these trials probably consisted of features related to the auditory stimuli and not features related to the somatosensory stimuli, resulting in less attention to the noxious stimulus and less pain. However, because the task was to localize targets, both spatial locations were part of the attentional set, as a result of which pain was not affected by spatial location.

Some may argue that this pattern of results is insufficient proof of the attentional set hypothesis. Indeed, one could argue that directing attention away from the somatosensory modality (modality-based selection) is sufficient in obtaining attentional control over pain, and that spatial location (spatial-based selection) is not important. This idea is unlikely, since previous studies have shown that spatially directing attention away from the location of the pain stimulus may diminish pain processing and pain (Dowman et al., 2004; Legrain et al., 2002; Mosely and Arntz, 2007; Van Ryckeghem et al., 2011).



In order to further test the attentional set hypothesis we designed Experiment 2 in which we also manipulated whether the spatial location of pain was in the attentional set or not. Participants were informed on each trial to identify a target from one particular perceptual modality (either auditory or somatosensory) at one particular location (either left or right) (see Figure 3). In this experiment, we expect an effect of both perceptual modality and spatial location on the experience of pain.

## Experiment 2

### Method

#### *Participants*

The sample consisted of 38 undergraduate students from Ghent University, who received course credits for participation (29 females; mean age =  $19.97 \pm 3.18$ , range 18-36). Inclusion and exclusion criteria, and agreement from the Ethics Committee, were applied in the same manner as in Experiment 1. Based on these criteria one participant was excluded from the analyses due to an anxiety disorder.

#### *Apparatus and stimuli*

Apparatus and stimulation parameters for non-painful vibratory and painful electrocutaneous stimuli were the same as in Experiment 1. Parameters for the auditory stimuli were also similar except for the fact that a second tone was added (540Hz; 64 - 66dB (A)) in addition to the 440-Hz tone. Both tones were presented through two loud-speakers (type, DELL A215) positioned approximately 35 degrees left and right from the middle.

#### *Experimental paradigm*

The experimental task was programmed and presented by the INQUISIT Millisecond software package (Inquisit 2.06, 2008) on an Excel computer (Pentium 4, 2.8GHz, 512MB) with a 60Hz, 17inch

colour CRT monitor. The experiment consisted of discriminating the somatosensory stimuli (painful vs. non-painful) or the auditory stimuli (high pitch vs. low pitch) at one particular spatial location.

Furthermore, both the somatosensory and auditory stimuli were presented exactly at the same time. In 50% of the trials participants were instructed to identify whether the tone was of a high or low pitch (auditory relevant trials; 50% high pitch, 50% low pitch). In the remaining trials participants were instructed to identify whether the somatosensory stimulus was painful or non-painful (somatosensory relevant trials). The relevant modality was cued by a word ("*somatic*" vs. "*tone*"). The location at which the stimulus of the relevant modality was to occur was cued by an arrow (pointing to the left vs. to the right). Modality and location cues were simultaneously presented in the centre of the screen (1000ms). Somatosensory and auditory stimuli were presented equally often at the same location (spatially congruent trials) and at the opposite location (spatially incongruent trials).

As in Experiment 1 there were four trial types: (1) spatially congruent/somatosensory relevant trials, (2) spatially incongruent/somatosensory relevant trials, (3) spatially congruent/auditory relevant trials, (4) spatially incongruent/auditory relevant trials (Fig 3). Each trial type was 'equi-probably' and

randomly presented at the left and right location. Participants were instructed to discriminate the target stimulus of the relevant modality and of the relevant location as indicated by the cues, as fast as possible by speaking aloud “*high*” or “*low*” for the auditory trials and “*tactile*” or “*pain*” for somatosensory trials. Response latencies were recorded by a voice key (REACSYS R-51). Response errors were encoded by the experimenter on a trial to trial basis. Self-report measures used in Experiment 2 were the same as in Experiment 1.

### INSERT FIGURE 3

#### *Procedure*

Experimental duration was approximately 45 minutes. Upon arrival in the laboratory participants were told that “we were interested in the influence of somatic stimuli on attention processes”. Furthermore, participants received task instructions and provided written informed consent. Participants were then seated in front of the monitor. Familiarization was the same as in the Experiment 1.

Next, participants performed 16 practice trials of the identification task. Only non-painful stimuli were administered during this phase. Trials were presented with an inter-trial interval of 1000ms. When an error was made, or response latency exceeded 7000ms, feedback was given by way of presenting a red screen for 500ms.

In the experimental phase, participants performed a total of 128 trials. The trials were presented randomly with the same inter-trial interval and maximum response latency as in the practice phase. In 96 trials the somatosensory stimulus consisted of a vibrotactile stimulus of which only 25% had to be rated on pain intensity and pain unpleasantness on the same scales as in Experiment 1. In only 32 trials an electrocutaneous stimulus was administered (in equal proportion for each trial type) of which 75% had to be rated on pain intensity and pain unpleasantness. Trials with vibrotactile stimuli were filler trials, for the same reasons as in Experiment 1.

#### *Data analyses*

Analyses were performed on trials containing electrocutaneous stimuli only. Trials with voice key errors and during which an incorrect response was given (11%) were removed from the analyses. All variables were normally distributed (all Kolmogorov-Smirnov  $Z < 1.03$ ,  $p > .10$ ). On each dependent variable, a repeated-measures analysis of variance (ANOVA) with Modality Relevance (somatosensory relevant/auditory relevant) and Location Congruency (spatially congruent/spatially incongruent) as within-subject factors was conducted. Effect sizes and 95% confidence intervals (95% CI) were calculated for dependent samples (Borenstein et al., 2009; Cohen, 1988).

## Results

### *Response latency*

Before performing analyses outliers were removed. Data with response latencies shorter than 200ms (anticipations) or larger than three standard deviations above the individual mean (outliers) were discarded from further analyses ( $\leq 2\%$ ). The ANOVA performed on response latency showed a significant main effect of Modality Relevance ( $F(1,36)=28.64$ ,  $p<.001$ ,  $d=0.88$ ; 95% CI =0.50:1.26), indicating that participants were slower on auditory relevant trials ( $M=1106$ ,  $SD=316$ ) than on somatosensory relevant trials ( $M=882$ ,  $SD=190$ ). No Main effect of Spatial Congruency ( $F(1,36)=1.56$ ,  $p>.10$ ,  $d=0.21$ ; 95% CI =-0.12:0.53) or interaction effect of Modality Relevance and Spatial Congruency ( $F(1,36)<1$ ,  $d=0.10$ ; 95% CI =-0.23:0.42) was found.

### *Self report data*

The ANOVA on self-report of Pain Intensity showed a significant main effect of Modality Relevance ( $F(1,36)=11.09$ ,  $p<.01$ ,  $d=0.54$ ; 95% CI =0.20:0.89), indicating that pain intensity ratings were significantly lower during auditory relevant trials ( $M=4.38$ ,  $SD=2.45$ ) than during somatosensory relevant trials ( $M=4.59$ ,

$SD=2.37$ ). No main effect of Spatial Congruency was found ( $F(1,36)<1$ ,  $p>.10$ ,  $d=0.13$ ; 95% CI  $=-0.20:0.45$ ). As expected, there was a significant interaction between Modality Relevance and Spatial Congruency ( $F(1,36)=5.76$ ,  $p<.05$ ,  $d=0.40$ ; 95% CI  $=0.07:0.74$ ). This interaction effect was further investigated by means of two paired sample t-tests. First, we tested the effect of Spatial Congruency when participants were instructed to identify the somatosensory target. Spatial Congruency had no effect ( $t(36)<1.03$ ,  $p>.10$ ,  $d=0.17$ ; 95% CI  $=-0.16:0.49$ ). Second, we tested the effect of Spatial Congruency when participants were instructed to identify the auditory stimuli. This difference was significant ( $t(36)=2.34$ ,  $p<.05$ ,  $d=0.39$ ; 95% CI  $=0.05:0.72$ ) indicating that participants rated the painful stimulus as less intense when the painful stimulus was at another location than when it was at the same location as the auditory target.

#### INSERT FIGURE 4

The ANOVA on self-report of Pain Unpleasantness showed a main effect of Modality Relevance ( $F(1,36)=5.83$ ,  $p<.05$ ,  $d=0.39$ ; 95% CI  $=0.06:0.73$ ), which indicated that pain unpleasantness ratings on auditory relevant trials ( $M=4.94$ ,  $SD=2.38$ ) were significantly lower than on somatosensory relevant trials ( $M=5.12$ ,  $SD=2.28$ ). No main effect of Spatial Congruency was revealed ( $F(1,36)<1$ ,  $p>.10$ ,  $d=0.03$ ; 95% CI  $=-0.29:0.36$ ). The interaction-effect of Modality

Relevance and Spatial Congruency failed to reach significance ( $F(1,36)=3.33$ ,  $p=.08$ ,  $d=0.30$ ; 95% CI  $=-0.03:0.63$ ).

## **Discussion**

In this experiment, we showed that the efficiency of attentional control over pain depends on the set of information that is considered task relevant by the participants. Indeed, in trials where participants were instructed to identify the tone target, noxious stimuli were judged as less intense. Importantly, this effect was especially pronounced when also the location of the pain stimulus was different from the spatial location kept in the attentional set. These findings again support the attentional set hypothesis and disconfirm the alternative hypothesis that the spatial location (spatial-based selection) may not be important in obtaining attentional control over pain.



## **General discussion**

In two experiments we investigated to what extent attentional control over pain depends upon the attentional set, i.e. the collection of task-relevant features that a person is monitoring in order to successfully perform that task. On each trial somatosensory and auditory stimuli were presented, either at the same location or at a dissimilar location. We manipulated attentional set by varying task instructions on each trial. In Experiment 1, participants were cued on each trial to localize either the somatosensory stimulus or the auditory stimulus that could appear on both locations. Self-reported pain intensity and unpleasantness were reduced when participants had to localize the auditory target. The location of the painful stimulus relative to the location of the auditory target did not affect pain. In Experiment 2, participants were cued on each trial to identify either the somatosensory stimulus or the auditory stimulus at a particular location. Again, pain intensity and unpleasantness ratings were reduced when participants were instructed to identify the auditory target. Now, however, the location of the painful stimulus relative to the location of the auditory target moderated the effect. Self-reported pain intensity was less when the painful stimulus was at a different location than the auditory target.

Overall, our findings imply that the interplay between attention and pain is not fully captured by simple resource/capacity models that merely focus on task difficulty and the effort needed to perform a task (McCaul and Malott, 1984). This finding is in line with recent theoretical advances which indeed have suggested that simple resource models are not sufficient to explain the interplay between attention and pain (Eccleston & Crombez, 1999, Legrain et al., 2009b, Johnson et al., 1998). In particular, our findings suggest that the experience of pain not only depends upon the availability of cognitive resources but also upon an individual's attentional set while pursuing goals (Legrain et al., 2009b; Van Damme et al., 2010). The less the perceptual features of a task are related to the features of a nociceptive stimulus, the less likely that pain is captured by attention during the performance of this task.

It is important to remind that attentional set is only one top-down variable that may affect pain. Indeed, the model of Legrain and colleagues predicts that the bottom-up capture of pain by attention is not only modulated by participants' attentional set. Also participants' level of executive functioning and the amount of attention deployed to achieve a goal (attentional load) may modulate attentional capture of pain (Legrain et al., 2011a; Legrain et al., 2009b; Verhoeven et al., 2011). Furthermore, the efficiency of top-down control over pain also

depends on the salience of the noxious stimulus, i.e., the extent to which the noxious stimulus contrasts from its environment or deviates from expectations. Therefore, one would expect that top-down control over pain will be less efficient when pain is very intense or novel (Eccleston and Crombez, 1999; Legrain et al., 2011a). In the present experiments we chose a noxious stimulus of relatively mild intensity in order to optimize the chances of finding top-down modulation by attentional control settings. More systematic research on the complex interaction between bottom-up and top-down processes is recommended. Interesting would be the investigation of the influence of differences in the saliency of the pain stimulus (e.g. novelty, intensity) on the ability to modulate attention by top-down variables (e.g. attentional set, executive functioning).

Our proposition that attention to pain depends partly on the degree to which task-relevant features of an ongoing task are distinct from the features of pain, may have implications. First, we may expect that explicit instructions to rate pain will keep features of pain in the attentional set, and thus may dampen effects of attempts to direct attention away from pain in some situations. To avoid this problem in our studies, participants rated their experience in only a limited proportion of trials. Future studies should be well aware of the putative devastating effects of instructions to rate painful experiences

in both experimental and clinical settings (Eccleston, 1995). Second, pain may be kept in mind, not only by instruction but because of its motivational relevance. It is known that those who are fearful about pain, or those who tend to catastrophize about pain, tend to ruminate about pain and how to get rid of it. We may then expect that pain-related features remain part of the attentional set, and that pain will easily be detected (Crombez et al., 1998; Goubert et al., 2004; Kirwilliam and Derbyshire, 2008; Notebaert et al., 2011). For those individuals, distraction from pain may be less beneficial (Crombez et al., 2005; Van Damme et al., 2010). In line with this argument, research has revealed that distraction often fails in those high in catastrophic thinking about pain (Goubert et al., 2004; Heyneman et al., 1990). Also research suggests that fear of pain (Peters et al., 2000) and catastrophic thinking (Van Damme et al., 2002) biases attention towards pain-related information. For those individuals, it might be important to increase the motivational relevance of the task in order to overrule the inclusion of pain-features in the attentional set (Verhoeven et al., 2010). Therapeutic strategies involving the manipulation of attention to relieve pain should therefore be fashioned in such a way that all pain-related information is kept as much as possible out of an individual's attentional set (e.g. by identifying and letting people pursue valuable goals, despite of pain).

The use of strategies in which patients are confronted with their pain (e.g. exposure strategies) might also be helpful as these may lead to a change of the negative meaning (e.g. catastrophic thinking; Leeuw et al., 2008) or controllability of pain. The result of this change in meaning or heightened feeling of controllability of pain is often a decrease in the presence of pain features in the attentional set. Indeed, patients become less occupied with pain and less threatened by the presence of pain/ pain-related information because they feel able to manage the pain.

The study has some limitations. First, pain was rated to some extent retrospectively. Although this might have resulted in memory biases (Redelmeier et al., 2003), post-pain ratings that are administered shortly after the exposure to pain are considered valid alternatives for online measurement (Koyama et al., 2004). Moreover, measurement during the task might be problematic as it might interfere with attention manipulations, because pain would then certainly be present in the attentional set (Eccleston, 1995). Second, participants were pain-free undergraduate students with whom experimental pain stimuli were used. One should be cautious in generalising these results to other populations. Further research is needed to establish whether our results can be replicated with a non-student sample experiencing clinically relevant pain. Third, the

interaction effect in study 2 failed to reach significance on the pain unpleasantness measure, albeit in the same direction as the pain intensity measure. This finding is similar to studies which have shown that the manipulation of attention primarily affects pain intensity, but influences pain affect to a far lesser degree (Kenntner-Mabiala et al., 2007; Keogh et al., 2000; Villemure and Bushnell, 2002; Villemure et al., 2003). It is however also possible that our pain unpleasantness measure was less sensitive and therefore lacked power.



### **Author contributions**

Experiments were designed by Dimitri Van Ryckeghem under supervision of Geert Crombez and Stefaan Van Damme.

Experiments as well as analyses were executed by the first author.

All authors discussed the results, commented on the manuscript and contributed to the process of writing and editing the manuscript.



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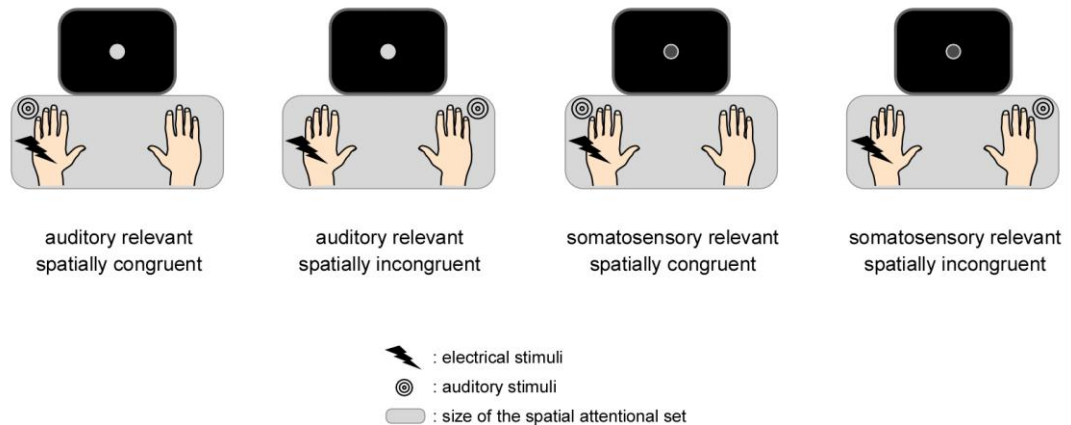


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## Figure Legends



*Figure 1.* The four possible trial types in Experiment 1. These are illustrated for noxious stimulation of the left hand only. The grey area represents the dimension of space which is relevant for the task. Because participants were instructed to localize the position of the stimuli on the hands, both hands are relevant and therefore both included in the participants' attentional set.

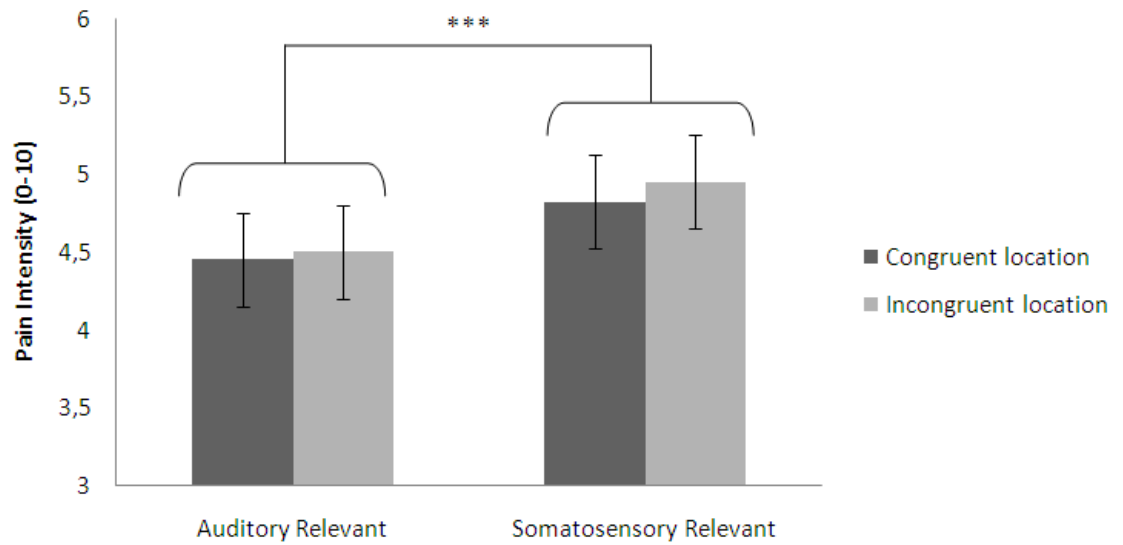
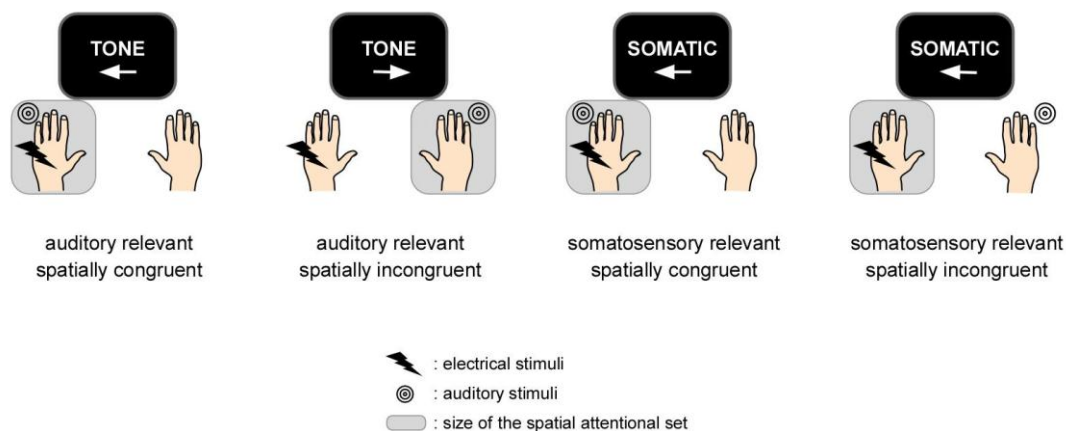


Figure 2. The mean intensity ratings of the noxious stimuli and standard error lines in Experiment 1. ( $^t=p<.10$ ;  $^*=p<.05$ ;  $^{**}=p<.01$ ;  $^{***}=p<.001$ .)



*Figure 3.* The four possible trial types in Experiment 2. These are illustrated for noxious stimulation of the left hand only. The grey area represents the dimension of space which is relevant for the task. Because participants were instructed to discriminate between auditory stimuli or between somatosensory stimuli at a specific location, which is cued by the arrow, only one hand was relevant and included in the attentional set.

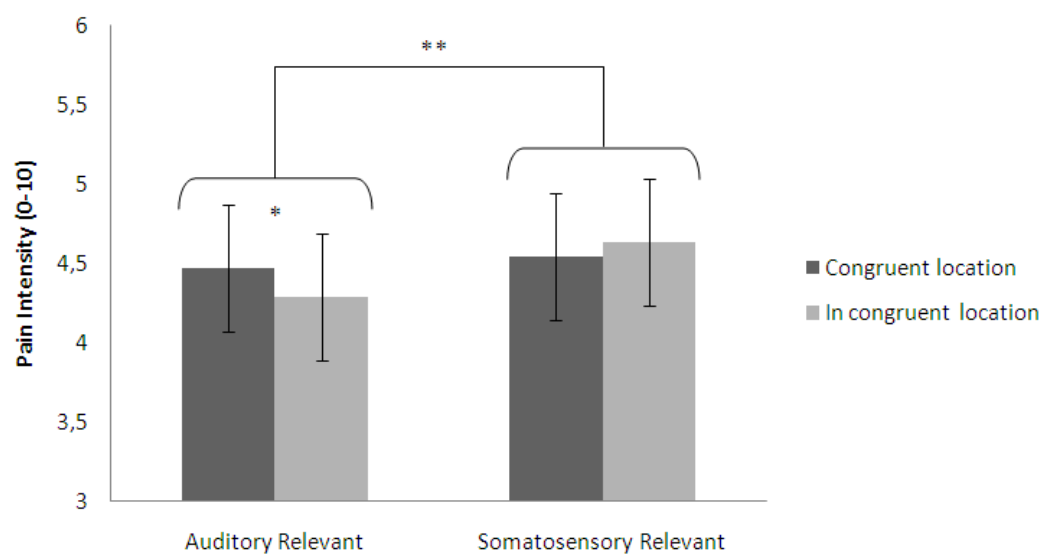


Figure 4. The mean intensity ratings of the noxious stimuli and standard error lines in Experiment 2. ( $t = p < .10$ ;  $* = p < .05$ ;  $** = p < .01$ .)